京都大学	博士（工学）	氏名	李　彧
論文題目	New Method Aiming at Comprehensive Evaluation of Low Impact Development：Case Study in Tianjin, China（環境影響の少ない都市計画の新たな総合的評価モデルの開発：中国天津市を例として）		

（論文内容の要旨）

Chapter 1 is the introduction of this research. Urbanization has been proved to have substantial impacts on flood control and water balance. In response, "Sponge city" refers to a city like a sponge, can be used to absorb the precipitation, enhance the rainwater and runoff purification, restore the water cycle, and during drought conditions that can release water from the reservoir and make use of. Despite of the progress made so far for the practice of low impact development (LID) techniques and practices, less research has been done to integrate the hydrologic performance with life cycle cost analysis. Since that, the central question of this research is as follows: How can we implement the LID devices more effectively in the future?

Chapter 2 introduced the impact of urbanization on the water system and the stormwater management. For areas that are urbanized rapidly, LID as an important part of sponge city has gained an important place in stormwater management and urban planning due to its capability and beneficial effects in restoring the original hydrological cycle. Three types of LID including grass swale, bio-retention and, permeable pavements were described in detail. Also storm water management in UK, Japan, and USA were overviewed.

Chapter 3 described the information about the study area in Tianjin, China. The study area, one of experimental sites for sponge city constructions in Tianjin, is a typical urbanized watershed with multi-functional land uses including industrial (55% of total), commercial (10%), residential (16%) and others. The total area is 22.78 km^2.

Chapter 4 described the principle of SWMM model and how to simulate LID in SWMM model. The model input and parameters of LID was also introduced. SWMM represents the hydrological and hydraulic processes occurring in each LID facility by dividing the facility into three layers: surface layer, soil or pavement layer and storage layer. The performances of different LID options on water quantity and quality were obtained.

Chapter 5 demonstrated that the rainfall distribution is the key issue for water balance and water budget. The temporal rainfall distribution patterns and Huff rainfall pattern of Tianjin and their impact on the watershed were studied. The Mann-Kendall test was used to detect significant changes based on historical data. In order to test that whether the GSMaP hourly rainfall dataset is also workable for this study area, the assessment on GSMaP was also performed over a four-year rainfall season comparing with gauge observed data in Tianjin. It showed that the rainfall pattern of Tianjin was derived using the Huff curve method showed that most of the precipitation in a rainstorm is concentrated in a short period of time, and peak flow of most rainfall events occur in the first two quartiles rain bands.

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Chapter 6 assessed the performance of each LID plan by using life cycle cost (LCC) analysis which is a method to identify the most cost-effective option by taking all the combined costs can be assumed to face over its lifespan and hydrological performance into consideration. It has been adopted in the field of water supply system inventory, evaluation of green and grey combined sewer overflow control strategies and permeable pavements design. It was found that LID facilities were more effective in smaller and shorter storms. In addition, permeable pavement had highest hydrological performance, while grass swale had greatest cost-effectiveness for single LID facility. The optimal LID scenario was the combination of permeable pavement ($0.52km^2$), bio-retention ($0.15km^2$) and grass swale ($0.32km^2$).

Chapter 7 indicated that the Analytic Hierarchy Process (AHP) provides a flexible and easily understood way of analyzing complicated problems. In this study, the hierarchical structure model of LID was built in terms of local conditions and requirements. And three main criteria including runoff quantity control, runoff quality control and additional benefits, and 9 indexes were selected to evaluate the performance of 7 LID design plans. Considering the runoff quantity control part, the permeable pavements was the most appropriate choice for single LID, followed by bio-retention and grass swale. The preferable order of LID based on the water quality control was grass swale, bio-retention, permeable pavements and the preferable order of LID considering additional benefits was bio-retention, permeable pavements, grass swale. Considering all the indexes, the most preferred single LID type is permeable pavements, followed by two single LID types closely competing with each other. It also reflected several trends that the combination of three types of LID is the most preferred choice.

Chapter 8 concluded the main findings and future work. The novel aspects of this research are (1) the identification of characteristics of rainfall pattern based on historical data in Tianjin, China, (2) the application of such an integrated LCC analysis to an urban area at watershed scale to select the best flood risk mitigation strategy from a set of potential LID alternatives, and (3) the inclusion of assessments on water quantity control, quality control and additional benefits by using AHP. Such an assessment tool is the first step towards more sustainable urban development and improved the robustness of decision-making procedure. In order to do the cost benefit analysis, the benefit curve and the damage curve with resulting flood costs under a large range of return periods of rainfall are necessary.

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（論文審査の結果の要旨）

従来の都市開発では、自然植生をはぎ取り、不浸透域の割合を増加させた結果、水循環を大きく変え、洪水発生リスクを増大させた。これを受け、スポンジのように水を吸収し、自然の水循環を回復する“Sponge City”構想が近年注目されている。環境影響の少ない開発(Low Impact Development: LID)は Sponge City”構想の根幹を担う技術である。本研究は、中国の 30 ある試験 Sponge City の一つである天津空港経済区を対象に、LID の効果を水文学的、経済的に評価するモデルを新たに開発したものである。

本研究では、3 種の LID 技術（生物学的調整池、草地、透水性舗装）を対象にその効果を検討している。LID の効果を検討した研究はこれまでにもあるが、水文・水質解析と経済評価、環境リスク分析を組み合わせた研究はほとんど例がない。本論文では、各国の都市開発や都市洪水対策についてのレビューをするとともに、3 種の LID 技術の特徴や効用を解説している。また、降雨波形分析では、時間雨量極値が近年増大していることや、上位 10%の豪雨において降雨イベントの序盤に降雨が集中していることなどが明らかになった。ライフサイクルコスト解析では、LID 技術により一定規模の豪雨については都市洪水を効果的に軽減できるものの、短期集中型の豪雨に対する効果には限界があることを示すとともに、実行可能な 7 種の LID 案の中で、3 技術を組み合わせた案が最も良いことを示した。また、3 技術を組み合わせた案が最善であることは階層分析法 AHP(Analytic Hierarchy Process)でも示された。

本研究の独創的な点は（1）中国天津市の過去の降雨観測データから、降雨波形の特性を明らかにしたこと、（2）統合的なライフサイクルコスト解析を流域スケールで開発区域に適用し、いくつかの LID 技術の組み合わせから最善な洪水リスク軽減策を選択可能にしたこと、（3）AHP を用いて、水量管理、水質管理、付加価値の評価を取り込んだこと、である。本論文で開発した評価ツールは、より持続的な都市開発への第一歩であり、確かな意思決定過程を可能にすることが期待され、学術上、実際上寄与するところが少なくない。よって、本論文は博士（工学）の学位論文として価値あるものと認める。また、平成 31 年 2 月 21 日、論文内容とそれに関連した事項について試問を行って、申請者が博士後期課程学位取得基準を満たしていることを確認し、合格と認めた。

なお、本論文は、京都大学学位規程第 14 条第 2 項に該当するものと判断し、公表に際しては、（平成 31 年 10 月 8 日までの間）当該論文の全文に代えてその内容を要約したものとすることを認める。